Final Report

Estuary Variance Map for *In Situ* Sample Station Placement

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Project Summary

The Gulf of Mexico Alliance has developed a Governors Action Plan for the five Gulf of Mexico states to address coastal ecological and societal issues. An element of that plan is to develop EPA mandated nutrient criteria for the estuaries around the Gulf of Mexico. Estuaries are very complex and dynamic ecosystems and physical sampling activities can be very expensive for state agencies with limited resources. To aid in the determination of the type and quantity of monitoring stations and to determine their most effective placement, a variance mapping tool was developed from a time series of NASA MODIS data products, specifically the MODIS Rrs_645 product. The Rrs_645 product is the atmospherically corrected MODIS 250 m red band. There have been numerous published studies demonstrating MODIS band 1 (645 nm) has a strong correlation with suspended particles, including phytoplankton. Absorption and scattering by suspended particles, phytoplankton and CDOM all contribute to the water clarity in an estuary and their spatial and temporal distribution within an estuary can be an indicator of dynamic processes affecting eutrophication.

In this study variance maps were created for Mobile Bay and the Mississippi Sound. These maps allow users to observe spatial and temporal variance in the reflectance data to determine the optimal type and quantity of monitoring stations and to determine their most effective placement. These water bodies have been chosen because there are several recent and current *in situ* sampling efforts. The variability maps were developed as an add-on to existing software developed by NASA at Stennis Space Center. The variability maps are accessible using the Coastal On-line Assessment and Synthesis Tool (COAST) for access by end users. The MDEQ is currently planning a pilot project to set nutrient criteria for at least one Mississippi estuary, although this project is currently on hold due to redirection of efforts related to the Deepwater Horizon Oil Spill. In addition, the University of Southern Mississippi has projects in the study area supporting the NOAA Northern Gulf Institute (NGI). In the coming months, the results of this project will be made available to the MDEQ and the University of Southern Mississippi for use in planning and evaluating ongoing studies.

Decision-making Activity

The Gulf of Mexico Alliance (GOMA) (http://gulfofmexicoalliance.org/) has developed a multi-year program plan, Governors Action Plan (GAP) which calls out five specific priority issues, one of which is the Nutrient Reduction priority issue. The Nutrient Reduction priority issue team within GOMA is developing an estuary study design intended to aid the participating states in the development of nutrient loading criteria for their estuaries with the end result being nutrient loading criteria to satisfy the Clean Water Act, administered by the U.S. EPA. To set reasonable and justifiable nutrient loading criteria, the impact on the estuary must be quantifiable in terms of specific end-points such as water clarity, eutrophication level, suitability for seagrass sustainability and other ecological endpoints. The monitoring requirements for each individual estuary are specific to the estuary and therefore must be adapted to obtain the most informative results.

The specific decision making activity will be the state agency's most informative and cost effective selection of *in situ* sampling stations to accomplish the goals of developing nutrient loading criteria. The Mississippi Department of Environmental Quality has submitted a proposal entitled "Development of Pilot Nutrient Criteria for a Mississippi Estuary" to the EPA Gulf of Mexico Program Office. This proposal has been selected for award. The current baseline for selection of monitoring stations is through extensive literature review and evaluation of estuarine geomorphology and physical characteristics. The MDEQ currently has no remote sensing capability, so they will be provided access to the COAST user interface for use in their proposed work. The improvement in decision-making derived from this effort is expected to be in the form of improved confidence in sample station site selection and overall monitoring effectiveness. A further quantitative improvement could possibly be in the actual cost reduction achieved through a more effective sampling program.

Results Summary

The project objectives were threefold. The first was to test the feasibility of producing a variance map from a time series of atmospherically corrected reflectance images derived from MODIS 250 m bands. The second was to test the validity of the variance map as compared to *in situ* measurements of in-water parameters. The third was to test the viability of the COAST software to support State and Federal agencies in obtaining the most effective site selection to establish nutrient and water quality standards.

The significance of the proposed work is expected to be important to state agencies responsible for implementing state and federally mandated monitoring programs, state and federal resource managers, researchers and students not only within the Gulf of Mexico but for estuaries world-wide. This could not only serve to reduce monitoring costs but allow station selection for improved understanding of estuarine processes. It could also expand the use of remotely sensed images from static snap shots to more dynamic assessment tools, leading to improved understanding of time dependent processes.

Overall the three primary objectives of this feasibility study have been met. Even though some of the technical issues could not be resolved within the scope of this effort the feasibility of producing the functional capability has been demonstrated. The technical issues that prevented a full implementation of this project have been identified and could be resolved with further efforts.

The first objective of computing temporal variances in the image data was accomplished. Atmospherically corrected Remote Sensing Reflectance data in MODIS Aqua band H1, i.e. 250 m red band (Rrs_645) for years 2000 to 2008 was output using SeaDAS v. 5.4 and subsequent images were produced that represented the mean, standard deviation, median, inter-quartile range, number of samples, and quality flags for Rrs_645 in each pixel. The output results represent 30 and 90 day composites taken at either 10 or 30 day time steps. These combinations were chosen as a compromise that considered the number of pixels available for computing statistics in any given time range, the number of files produced, and the anticipated temporal and spatial variability in the image data results.

The second objective to compare remote sensing results with in situ measurements was also accomplished. For the purpose of this work total suspended matter (TSM) was used as the parameter of choice due to availability of data sets within the study area. Results indicated that the variability in the remotely sensed data was comparable to that observed in the in situ measurements over one annual sampling effort. The remotely sensed data provided an indication of both spatial and temporal variability that was not being captured by monthly in situ samples alone. A review of remotely sensed variability data in the vicinity of identified station locations demonstrated that there were differences in temporal variability across regions in the estuary. The Coefficient of Variation (COV) was used to compare variability in Rrs_645 relative to that in TSM.

The third objective of implementing the variance mapping capability in COAST was met in principle. The ability to create variability maps in real-time from a COAST user interface was not implemented due to a number of security requirements related to accessing data on a NASA computer via an internet browser. To circumvent this issue the variance maps were pre-computed as described below and the resulting images were selectable by the user based on dates of interest, desired time step and desired time range over which data was composited. The original objective was therefore only limited in the ability of the user to select an exact date and an exact number of days for producing the data variance map.

As of this writing the data and COAST software have not yet been made available to MDEQ for their evaluation. The MDEQ has suspended efforts to begin a study in St. Louis Bay due to the recent Deepwater Horizon Oil Spill. Efforts to provide MDEQ with access to the COAST software and data will continue. In lieu of MDEQ the system will be used by a University of Southern Mississippi (USM) student in the development of station selection for a Master’s Thesis. USM has significant research interests in the location of the study area and is a member of the NOAA funded Northern Gulf Institute and participates in GOMA activities related to the Gulf. Communication with MDEQ will continue in order to facilitate a future transfer of this capability.

Background

Estuaries are regions of highly complex physical, biological and chemical processes. Variability of biological and physical processes within an estuary has long been established (Cloern 1987; Jassby, Cole et al. 1997; Cloern 2001; Han and Jordan 2005; Lehrter 2008). Estuaries are the mixing interfaces between freshwater inflows and the high salinity marine environment of the continental shelf (Day, Hall et al. 1989).

Estuaries are valued as highly productive regions serving as sanctuaries for developing fish and shell fish as well as recreational areas for fishing and water sports. Many estuaries of the U.S. are considered impaired due to eutrophication associated with excess nutrients, dredging and channeling and erosion. The EPA clean water act section 303 calls for states to develop nutrient loading criteria to halt and reverse the impact of eutrophication.

In order to set nutrient criteria that are meaningful as well as economically feasible, responsible state agencies are initiating monitoring programs to establish baselines for such eutrophication indicators as concentrations of chl *a* associated with phytoplankton blooms and concentrations of suspended sediments associated with erosion, dredging and resuspension.

In the highly complex estuaries the physical forcing functions of freshwater inflows, tides, wind forcing and natural and man made physical features all contribute to the mixing of fresh and saline waters. The physical forcings also create regions of variability for biogeochemical processes.

In order to implement a monitoring program that effectively captures the variability, ranges of water quality parameters of interest, e.g., chl *a* and total suspended matter (TSM), a suitable sampling strategy should be developed. In many published estuarine studies, discussion of methods includes descriptions of measurements and processes, but very little on selection of sampling strategies. This can lead to incorrect conclusions if sampling stations miss key events and natural variability within the estuary.

In order to develop an effective and economically feasible sampling strategy some knowledge of estuarine conditions and processes should be known. A statistical approach (Jassby, Cole et al. 1997) to evaluate the variability of salinity, chl *a*, and TSM in San Francisco Bay, CA, demonstrated that variance in measurements in horizontally homogeneous regions of an estuary is inversely proportional to the square of the number of stations, n, and the greatest reduction in variance occurred as n increased to 10. For n > 10, the reduction in variance decreased as n approached infinity. These results clearly indicate there is a minimum number of sampling stations required but there is a definite point of diminishing returns when exceeding that number.

Study Area

The Mississippi Sound and Mobile Bay are to be the focus areas of this study. This Mississippi Sound is approximately 105 km long and ranges from 4 to 20 km wide (Otvos and Carter 2007). The Sound is bordered on the north by the coast line of Mississippi and Alabama west of Mobile Bay. The southern boundary consists of a chain of barrier islands that stretch from Cat Island in the west to Dauphin Island on the east end. There are six islands of various length in the chain, each separated by open water passes of various width and depth. Mobile Bay and Mississippi Sound are linked near the mouth of Mobile Bay through Pass aux Herons, with the Sound receiving about 15% of the fresh outflow of Mobile Bay (annual average ca. 340 $m^3\ s^{-1}$). The Sound is also fed by three watershed basins including the Pearl River Basin, Pascagoula River Basin and the Coastal Streams Basins, all contributing an annual average fresh water flow of ca. 520 $m^3\ s^{-1}$ (USGS, http://ms.water.usgs.gov). The west end is connected to Lake Pontchartrain, LA, contributing only about 15 $m^3\ s^{-1}$, (USGS, http://waterdata.usgs.gov) The Sound is influenced by a diurnal micro tide (< 1 m). The mean water level is also strongly influence by prevailing winds which also cause resuspension of bottom sediments.

Mobile Bay is fed by the sixth largest watershed in the continental U.S. Average fresh water flow is 2245 $m^3 s^{-1}$, ranging from 500 to 13,000 $m^3 s^{-1}$(Bianchi, Pennock et al. 1999). Mobile Bay is also strongly influenced by a diurnal micro tide. Mobile Bay is a drowned river valley approximately 20 km from north to south and averages about 12 km in width, narrow in the north, widening to the south, with narrow passes to the Gulf of Mexico and the Mississippi Sound. Both the Mississippi Sound and Mobile Bay are rather shallow averaging about 3 m in depth. Mobile Bay is also highly influenced by wind forcing (Park, Kim et al. 2007).

The Mississippi Sound is relatively un-studied compared to Mobile Bay, which continues to be the focus of numerous studies. The Mississippi Sound and Mobile Bay system is a highly variable system influenced by diurnal tides as well as seasonal trends. Total fresh water inflows vary seasonally and can range from 500 to 19000 $m^3 s^{-1}$. Salinities range from near zero at the fresh water inflows to near 30 at the passes to the Gulf of Mexico. Production in Mobile Bay ranges from 194-325 $gCm^{-2}y^{-1}$, with a seasonal pattern and chl *a* concentration ranges from 2-12 $\mu g\ l^{-1}$ and bloom concentrations up to 50 $\mu g\ l^{-1}$, with no seasonal pattern and high spatial variability throughout the Bay (Bianchi, Pennock et al. 1999).

Approach

Because estuarine processes are both spatially and temporally variable, the NASA MODIS sensors currently flying on the Aqua and Terra satellites have been selected as the data sources for the variance map application. The MODIS sensors provide near daily coverage of the study area, with a before noon and an afternoon pass. Because of high cloud probability in the warm seasons, data from the two sensors can be combined to form a single cloud free or reduced cloud coverage image. The 250 m bands were chosen to achieve the highest possible spatial resolution, thus providing the highest spatio-temporal combination of available satellite sensors.

In addition, the MODIS instrument was designed with higher radiometric sensitivity than other Earth observing sensors such as the Landsat Thematic Mapper (Hu, Chen et al. 2004). It is also recognized that there can be high spatial variability of water characteristics within each pixel (Yuan, Dagg et al. 2005).

The red or 645 nm MODIS band was chosen due to the historic use of the red and near infrared (NIR) bands of MODIS and other Earth observing sensors to observe suspended particles in the water column. The high absorption in the red spectrum by water (Smith and Baker 1978) limits the response due to bottom reflectance. The relatively stronger blue green vs. red absorption by chl *a* and colored dissolved organic matter (CDOM) leaves the red band signal primarily controlled by backscattering of suspended particles near the surface. The response in the MODIS 645 nm band has been shown to be highly correlated with turbidity (Chen, Hu et al. 2007) and total suspended matter (TSM) (Hu, Chen et al. 2004; Miller and McKee 2004).

It is recognized that correlation with TSM does not account for varying contributions between suspended sediments and phytoplankton. Because the desired result is total variability in the water column, there is no effort to distinguish between the two.

To remove variability in the time series of MODIS images due to intervening atmospheric absorption and scattering, a method of atmospheric correction was applied. Three approaches were evaluated including the MODIS MOD09 product, the NIR method for highly turbid waters by (Wang and Shi 2007), available in SeaDAS (Baith, Lindsay et al. 2001), and the NIR "black pixel" correction method widely used in remote sensing studies. Test results show the methods available in SeaDAS (Baith, Lindsay et al. 2001) (http://oceancolor.gsfc.nasa.gov/seadas/.) resulted in higher spatial noise levels overall but ease of application within the scope of this project made method of Wang and Shi (2007) in SeaDAS the best choice. The product used to obtain the estuary variance map is the atmospherically corrected remote sensing reflectance Rrs_645.

Variance Maps

Because of local internet security issues governing access to data servers via web applications, a real-time, user directed variance map production capability was not implemented. Instead the variance maps were pre-computed based on planned user options and access to the resulting image data was implemented in the SSC developed COAST web application (See COAST description below). Pre-computed variance map data files could be stored with the web application for direct access by the user. The variance maps were created based on methods that would have been made available to the users directly. These are described below.

The Estuary Variance statistics calculations were performed with MODIS 250-m data from the 645-nm band that had been processed to remote sensing reflectance with SeaDAS. A MATLAB function was written to reproject the remote sensing reflectance data and corresponding quality data layers to a geographic grid as follows:

1) From each hdf file, the 645-nm reflectance band and the quality flags for land, high satellite zenith angle, clouds, and severe sun glint are extracted
2) Reflectance and quality data are reprojected to a regular grid using the "imbedm" function
3) Artifact gaps (caused by imbedm) in the reflectance data corresponding to good data (not quality flagged) are filled using the cubic interpolation
4) A new quality layer flagging the locations of the pixels filled in the step above is created
5) Filled surface reflectance data is exported to png format for import into COAST

The re-projected, filled reflectance data and quality layers are stored in .mat file format for use as input into a statistics calculation code that screens the data for quality and outliers prior to calculating statistics over moving time windows. Two different length time windows, 30 days and 90 days, were used. The 30-day time window stepped through the time series of data in 10-day increments, while the 90-day window stepped in both 10-day and 30-day increments. The resulting statistics images and additional quality information are stored in png format for import into the COAST viewer. The statistics code processes each time window of gridded reflectance data as follows:

1) Each image in the time window is screened to ensure that more than 5% of the pixels have good or filled reflectance data (those that do not are set to NaN to remove them from further calculations)
2) Each image median is calculated and images whose median value is more than 4 standard deviations away from the mean of all image medians in the time window is set to NaN
3) On a per pixel basis, non-quality flagged values (not land, sun glint, high zenith angle or clouds) that are more than 4 standard deviations away from the mean value of that pixel over the entire time window are set to NaN.
4) On a per pixel basis, the following statistics are generated over the time window for every non-quality flagged, non-NaN value: Mean, Standard Deviation, Median, and Interquartile Range (75 percentile value – 25 percentile value)
5) Quality layers are also created on a per pixel basis:
    a. Number of Points considered: number of non-NaN points in the time window, regardless of quality flags
    b. Number of Good Points: number of non-NaN, non-quality flagged points actually used to calculate statistics
    c. Percent Fill: The percentage of filled pixels used to calculate statistics (based on the time window)
    d. Percent Cloudy: The percentage of cloudy pixels removed from the statistics calculation (based on the time window)
6) All four statistics and four quality layers are exported to png files

Validation and Analysis of Results

NASA has funded two recent studies of Mobile Bay that include the collection of *in situ* TSM samples, along with a variety of other parameters, at fixed stations throughout Mobile Bay and in the Gulf of Mexico outside Mobile Pass. In addition, the University of Southern Mississippi (USM), Department of Marine Science has been conducting a sampling transect extending from the Bay of St. Louis, past Cat Island and south of the barrier island chain. This data, along with additional data collected by USM for this study, and other published data was used to evaluate both the validity and utility of the variance maps.

Four sample stations were selected from the available *in situ* data sets to compare with data extracted from the computed variance maps. Two stations were selected in areas where *in situ* TSM data indicated low concentration and variability (GOM7 and GOM15) and two stations where *in situ* data indicated high concentrations and variability (MBbay1 and MBay10). Total suspended matter (TSM) samples from these stations had been collected monthly between November 2007 and August 2008 (Fig. 1). Mean, standard deviation and coefficient of variation were computed for TSM at each station. Mean, standard deviation, and coefficient of variation were obtained from pre-computed Rrs_645 variance maps derived from pixels at each station location. The pixel reflectance values were taken from the 30 day composite, 10 day step images.

Reflectance means and standard deviations from the 30 day composites are plotted with the TSM values for the period of interest for comparison (Figs. 2 – 5). Temporal variations in mean reflectance and TSM appear to track each other in most cases thus demonstrating a reasonable expectation of co-variability. Direct correlation between reflectance and TSM was not possible due to lack of days with co-incident satellite and *in situ* data for the period. (Keep in mind it was not the objective of this work to develop an accurate MODIS TSM data product.) It should be noted that in stations MBay1 and MBay10 (Figs. 2, 3) the magnitude of TSM is about three times that of stations GOM7 and GOM15 (Figs. 4, 5) and the reflectance values scale similarly.

Comparison using mean values demonstrates that the reflectance images correctly capture the temporal changes in TSM values for stations MBay1 and MBay10. The reflectance mean images demonstrate that there is some temporal variability that is being missed by the monthly *in situ* sampling but the large scale temporal changes are comparable.

At Gulf stations GOM7 and GOM15 the magnitudes and range of TSM values are much lower than stations inside Mobile Bay. This decrease in measurement extremes makes detecting any temporal patterns or cycles difficult. Similar results are observed in the mean reflectance data (Figs. 4, 5). There is little temporal co-variation between TSM and reflectance values at these stations, indicative of a steady state condition with low impact forcing influencing suspended particles on a day to day basis.

Using only the mean reflectance images to evaluate sample placement provided both useful indications of magnitude and temporal variability of TSM at the sample stations tested. These results also indicate that a higher temporal sampling rate could provide more information about temporal cycles inside Mobile Bay. Variability at stations MBay1 and MBay10 do not appear to be strongly co-varying indicating more station locations may be called for. Conversely, TSM at Gulf stations appears to have a lower range of variability, suggesting fewer temporal samples and fewer stations might be adequate to characterize conditions.

COV was used for comparison to eliminate differences in scaling between the numeric values of the TSM and reflectance data (Figs. 6 – 10). The comparison is based on the annual variability determined from the *in situ* data which results in a single value for the period vs. the variability observed in each 30 day window at 10 day steps through the sample period obtained from the MODIS data.

Results indicated that for three of the four stations evaluated, the COV computed for TSM is similar in magnitude to COV obtained from the reflectance images (MBay1, GOM7, and GOM15, Figs. 6, 8, 9). The COV from TSM at MBay10 (Fig. 7) is nearly twice that observed in the reflectance data. This is due to a single outlier in the TSM values. When this outlier is removed the TSM COV is within the magnitude of COV observed in the reflectance data (Fig. 7).

In comparing a single value of COV derived from the temporally sparse TSM values obtained at each station from the sample period vs. 10 day stepped reflectance values acquired over 30 days (Figs. 6 – 10) results indicate that the reflectance images are indicative of the TSM variability at each station. In addition, this comparison demonstrates that at each station location there are times during the study period that variability increases beyond what is being captured by monthly sampling.

Results presented here clearly demonstrate the utility of using mean, standard deviation and COV image reflectance data for evaluating variability within coastal estuaries. An end user can identify spatial and temporal differences in ranges in magnitude, standard deviation and COV everywhere within a region of interest over a selected time period. These results should allow anyone planning an estuarine study to gain a better sense of where and how often to collect samples that will best characterize spatial and temporal variability.

COAST results

NASA has developed a software tool called World Wind that allows mapping and overlaying of image and discrete data over geographically registered locations using a World Wide Web image display capability. The software is open source, meaning that all code is available for modification and introduction of new capabilities. This software forms the basis for the COAST software developed by personnel at NASA Stennis Space Center. The COAST software incorporates additional modules developed by individuals and agencies around the world as well as by local programmers.

The user interface for the variance mapping application was implemented in the COAST software. It allows the user to access and display the individual images created as described above (Figs. 11, 12). For each day of the time step eight data products derived from Rrs_645 can be selected for display including mean, standard deviation, median, inter-quartile range (IQR), number of samples available during the period selected, number of samples used for each calculation, cloud flag, and fill quality flag (see description above). The quality flags allow the user to assess the significance of the statistical results presented in the images.

COAST will also allow the user to display existing station locations accessible via the internet, e.g. the NOAA National Data Buoy Center. Spatial variability in the study area is observable by visual inspection of the images. Temporal variability is observable by time stepping through the pre-computed variance map images. Future work would investigate the potential to extract reflectance data directly from the images for analysis.

Feasibility Criteria

Feasibility of this project is primarily related to the availability of cloud free pixels over a given time period within the subject estuary. The variability within an estuary is a function of within estuary processes as well as external forcings. The time scale of various external forcing processes could be daily (tides, winds, clouds), episodic (1 day to a few weeks) (prevailing winds, weather front passages, storms), seasonal (spring floods, seasonal droughts), annual (climatic changes, subsidence, sea level rise, watershed evolution).

Because the variance map is a statistics based product, the quality and interpretation of the results is dependent on the number of samples available for a given time period. The availability of data during certain types of forcing events such as storms is limited and similarly seasonal cloud cover especially during the summer is problematic. Therefore the availability of data in statistically significant quantities to produce a seasonal time scale variability product will be a factor in interpretation of results. Shorter duration products such as monthly or weekly are goals, however experience has shown that summer months sometimes allow for only a few satellite images per month.

Finally, the user interface and overall value to the end user will determine the ultimate success of the project. Developing a workable web-based interface, web initiated analysis software and suitable storage arrangements for the processed image data is key to connecting end users to a remote sensing tool. The current implementation allows for reasonable access to data allowing for useful interpretation of results.

Results for this project with respect to availability useable pixels at a given location over a given time period were set by fixing the data window at 30 days. Actual number of pixels used in the computations was preserved allowing the user to assess the robustness of the results. The analysis above clearly shows that even with a 30 day window additional variability was detected beyond what was possible with the temporally sparse *in situ* sample data. The user interface developed here, in light of the security issues, is still quite useful for the intended purpose. The flexibility for selecting user defined dates and time windows was not implemented but sufficient data was pre-computed to allow for reasonable time resolutions, i.e. 10 day time steps.

Overall it is expected that users will find this tool useful, even within the restricted capabilities. Further, it should be possible to add additional analysis tools that will allow greater utility of this data.

Figures

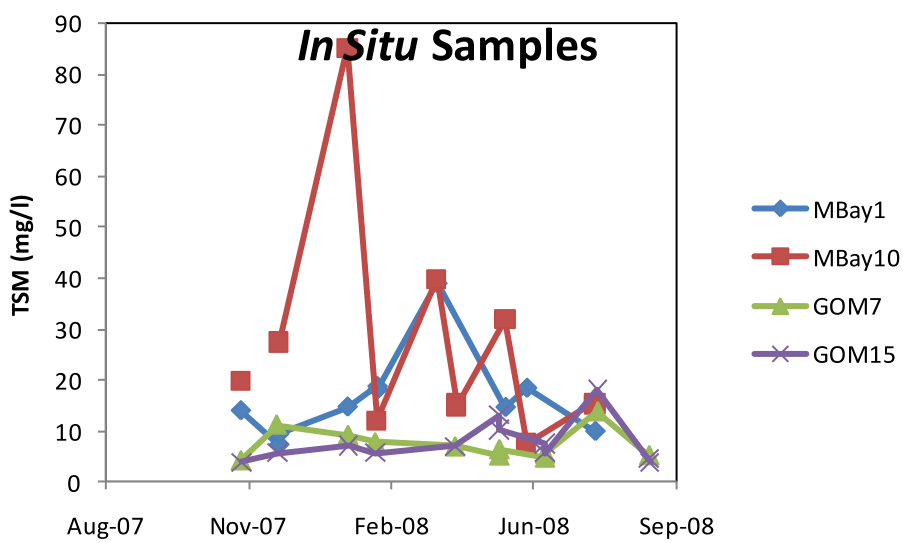

Figure 1. Monthly TSM samples from four stations. MBay1 and MBay10 are inside Mobile Bay. GOM7 and GOM15 are outside the mouth of Mobile Bay.

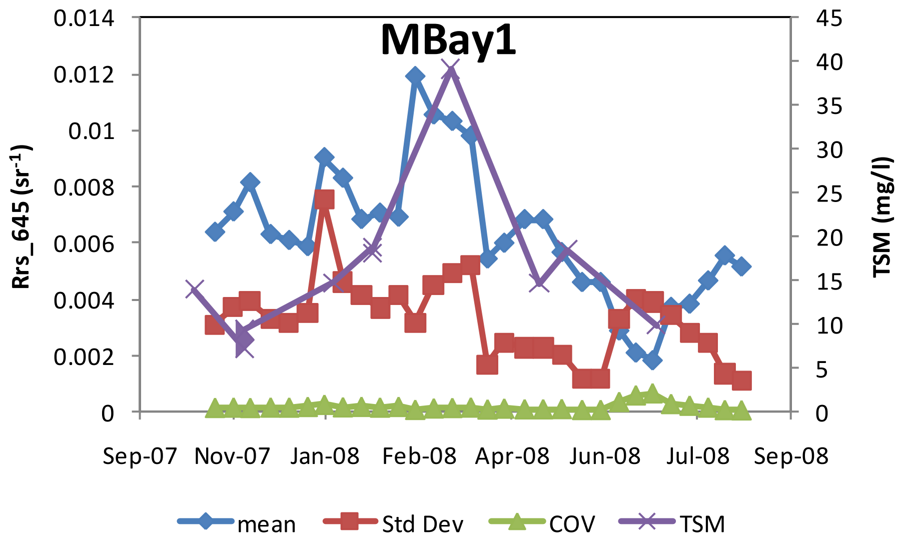

Figure 2. Left axis is Rrs_645 mean, standard deviation and COV from 30 day window taken in 10 day steps. Statistics are taken from all qualified pixels over station MBay1 within the 30 day window. Right axis is TSM obtained from insitu samples.

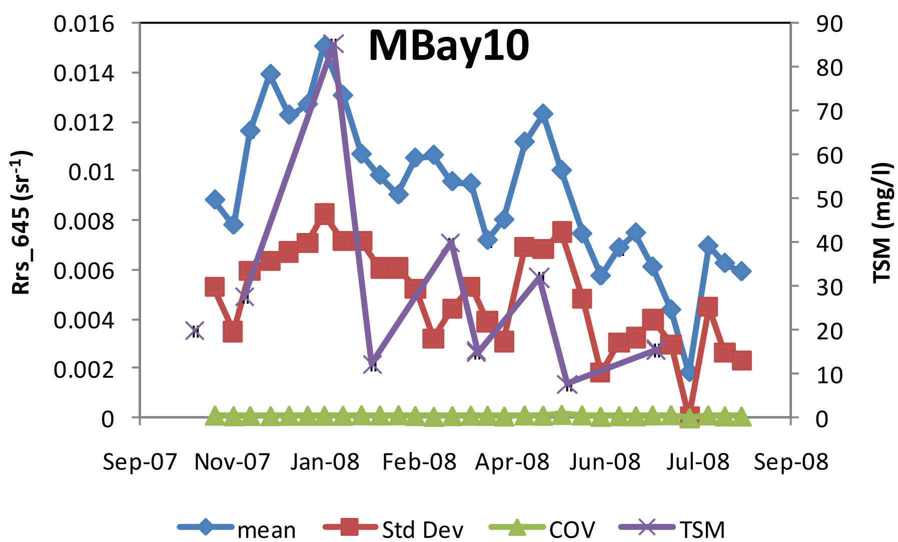

Figure 3. Left axis is Rrs_645 mean, standard deviation and COV from 30 day window taken in 10 day steps. Statistics are taken from all qualified pixels over station MBay10 within the 30 day window. Right axis is TSM obtained from insitu samples.

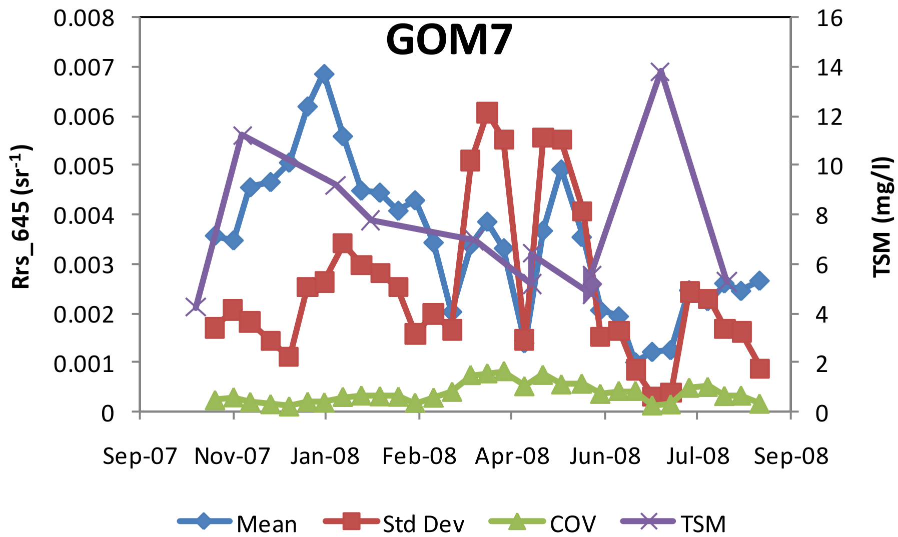

Figure 4. Left axis is Rrs_645 mean, standard deviation and COV from 30 day window taken in 10 day steps. Statistics are taken from all qualified pixels over station GOM7 within the 30 day window. Right axis is TSM obtained from insitu samples.

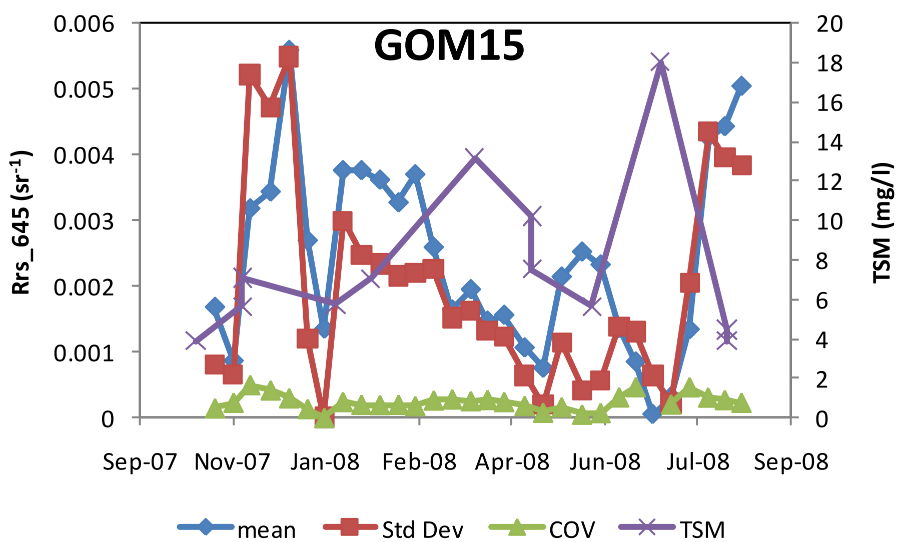

Figure 5. Left axis is Rrs_645 mean, standard deviation and COV from 30 day window taken in 10 day steps. Statistics are taken from all qualified pixels over station GOM15 within the 30 day window. Right axis is TSM obtained from insitu samples.

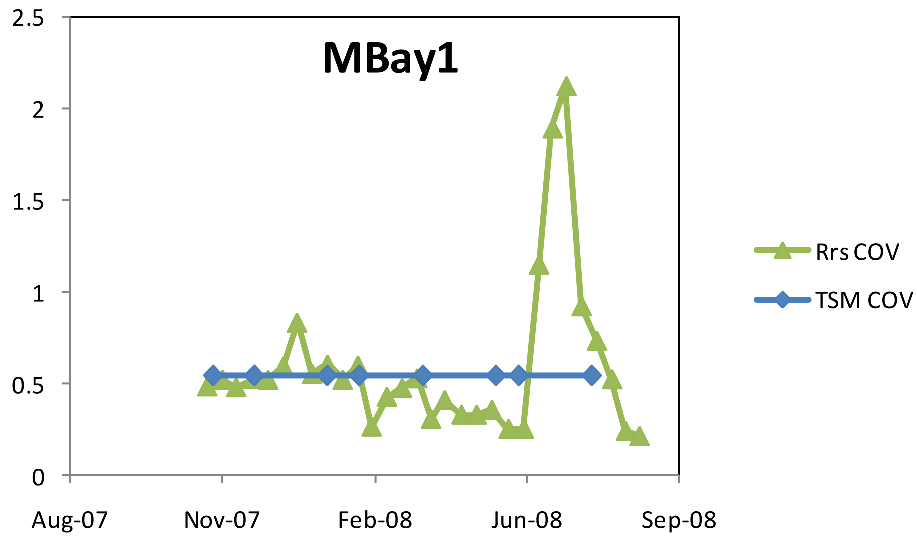

Figure 6. Coefficient of Variation (Rrs COV) computed from mean and standard deviation of Rrs_645 data at each 10 day time step (see Fig. 2). TSM COV is from mean and standard deviation of all in situ samples at Station MBay1. Note: TSM COV is constant because it is derived from sample data from the entire period.

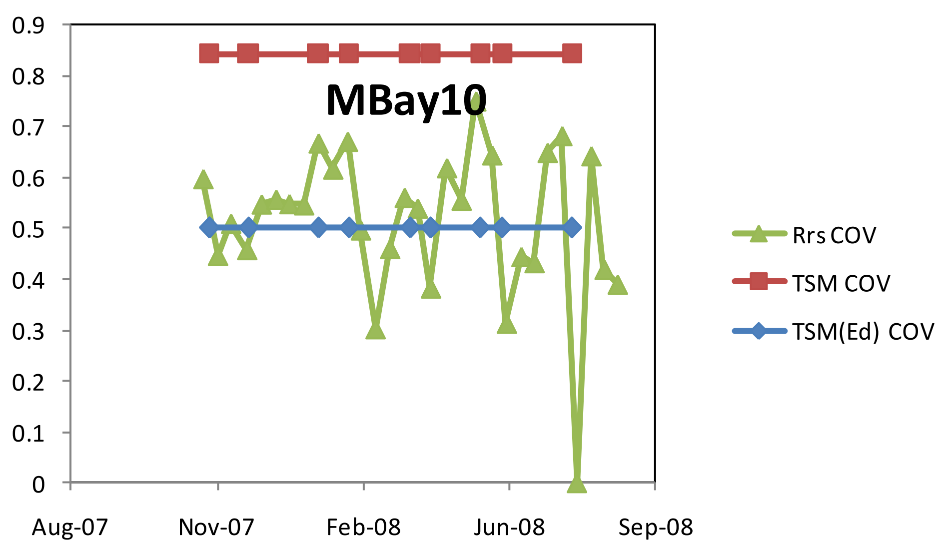

Figure 7. Coefficient of Variation (Rrs COV) computed from mean and standard deviation of Rrs_645 data at each 10 day time step (see Fig. 3). TSM COV is from mean and standard deviation of all in situ samples at Station MBay10. TSM(Ed) COV is computed from TSM data with one outlier removed (See text). Note: TSM COV is constant because it is derived from sample data from the entire period.

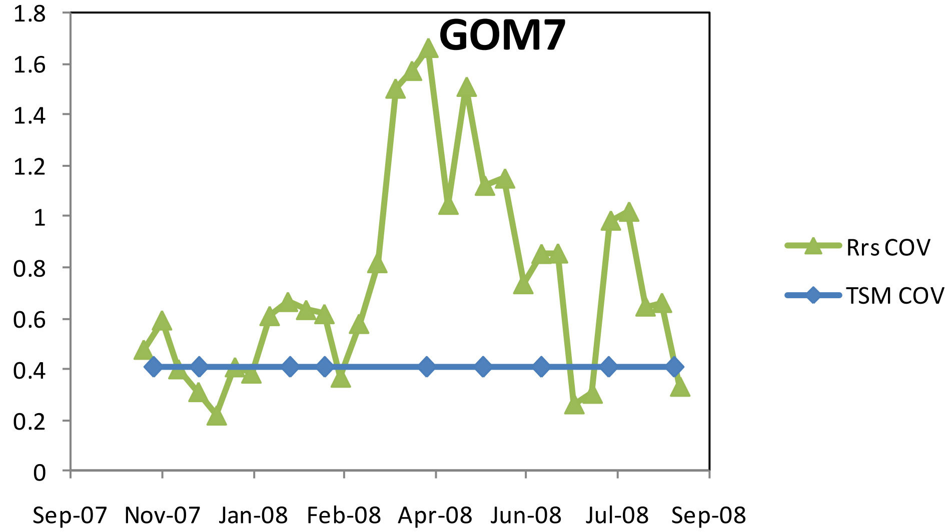

Figure 8. Coefficient of Variation (Rrs COV) computed from mean and standard deviation of Rrs_645 data at each 10 day time step (see Fig. 4). TSM COV is from mean and standard deviation of all in situ samples at Station GOM7. Note: TSM COV is constant because it is derived from sample data from the entire period.

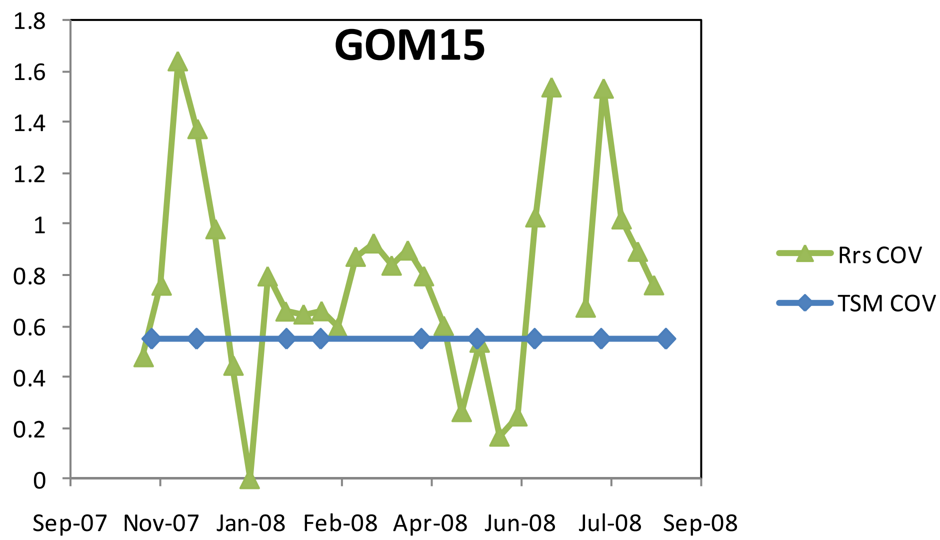

Figure 9. Coefficient of Variation (Rrs COV) computed from mean and standard deviation of Rrs_645 data at each 10 day time step (see Fig. 5). TSM COV is from mean and standard deviation of all in situ samples at Station GOM15. Note: TSM COV is constant because it is derived from sample data from the entire period.

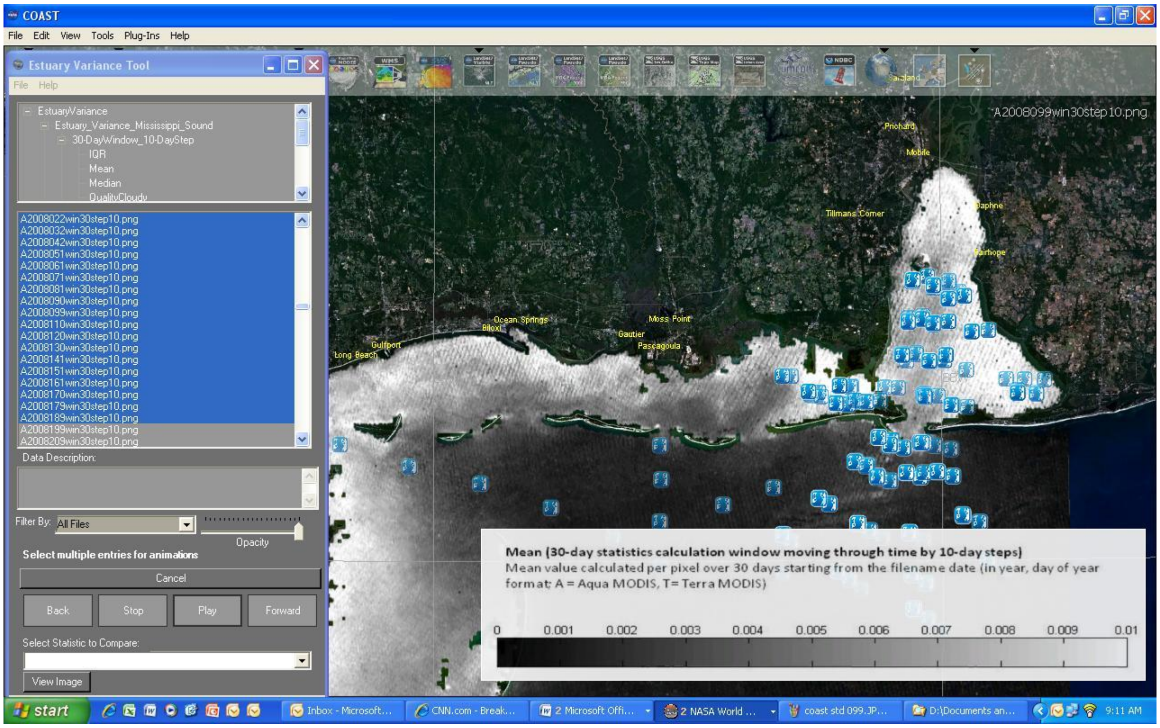

Figure 10. Screen grab of COAST software displaying Rrs_645 mean obtained from 30 day window surrounding day 099, 2008. Blue icons represent *in situ* sample locations. Cursor can highlight station icons to obtain actual TSM values for each sample date. Window on left is Estuary Variance Tool user interface.

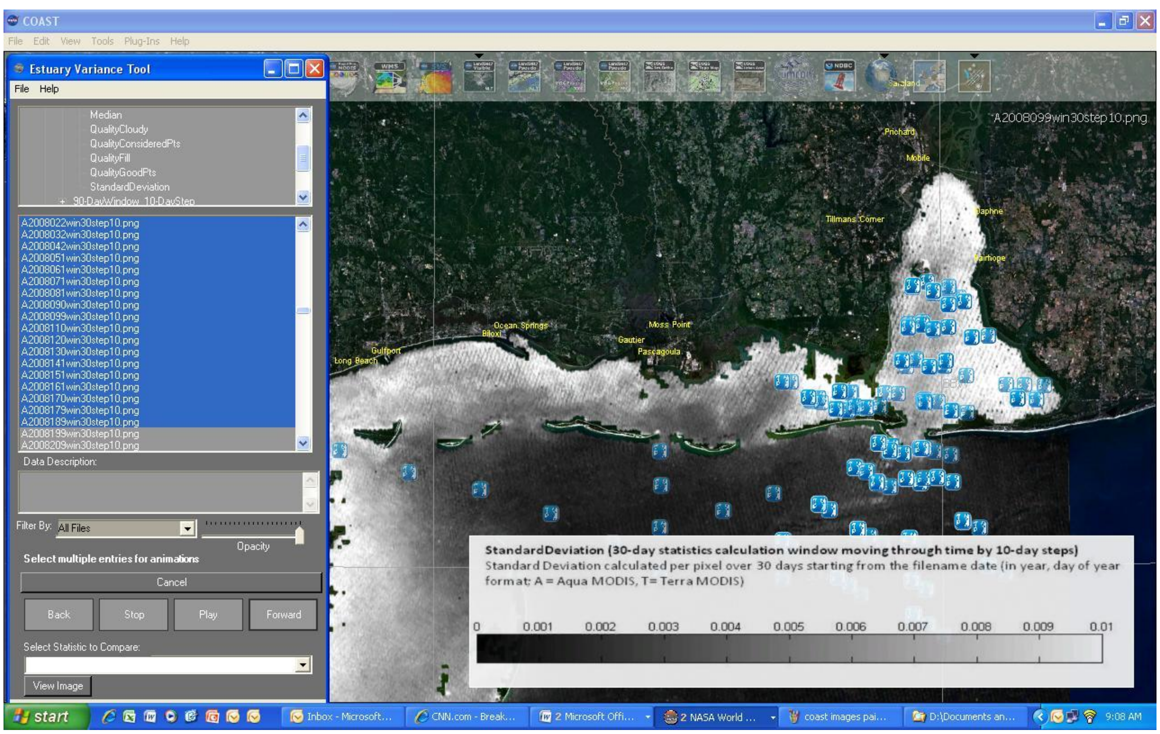

Figure 11. Screen grab of COAST software displaying Rrs_645 standard deviation obtained from 30 day window surrounding day 099, 2008.

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